Great Basin Naturalist 52(4), pp. 313–320

PLANT AGE/SIZE DISTRIBUTIONS IN BLACK SAGEBRUSH (*ARTEMISIA NOVA*): EFFECTS ON COMMUNITY STRUCTURE

James A. Young[1] and Debra E. Palmquist[1]

ABSTRACT.—The demography of black sagebrush (*Artemisia nova* Nelson) was investigated in the Buckskin Mountains of western Nevada to determine patterns of stand renewal in sagebrush communities currently free from wildfires. Biomass sampling was conducted to develop growth classes that reflected apparent age of the shrubs. The density of black sagebrush plants was twice that of basin big sagebrush (*A. tridentata* ssp. *tridentata* Nutt.) in adjacent communities on contrasting soils (2.2 versus 1.1 plants per m^2). Black sagebrush accumulated only 75% as much woody biomass as big sagebrush. Regression equations were developed and tested for predicting total woody biomass, current annual growth (CAG), and leaf weight of black sagebrush plants. Apparent age classes were developed both for the black sagebrush plants and the sub-canopy mounds on which they grew. Discriminant analysis was used to test this classification system. Plant succession, apparently controlled by nitrate content of the surface soil, appeared to eliminate the successful establishment of black sagebrush seedlings on the mounds. After the shrubs die, the mounds eventually deflate. We propose that mounds reform around shrub seedlings; but because seedling establishment is so rare in these communities, this could not be verified.

Key words: biomass, shrub succession, desert soil formation, soil nitrate, black sagebrush, Artemisia nova.

Black sagebrush (*Artemisia nova* Nelson) is one of the dwarf sagebrush species which collectively constitute about half the sagebrush vegetation in Nevada (Beetle 1960). Black sagebrush plays a dominant role in a number of plant communities in the Great Basin (Zamora and Tueller 1973). Rarely does black sagebrush share dominance with another species of *Artemisia*. In the section Tridentate of the genus *Artemisia*, black sagebrush is perhaps the species most adapted to arid environments. Black sagebrush is closely associated with shadscale [*Atriplex confertifolia* (Torr. & Frem.) Wats.] dominated landscapes (Blaisdell and Holmgren 1984). The browse of black sagebrush is highly preferred by domestic sheep (*Ovis aries*), pronghorn (*Antilocarpa americana*), and Sage Grouse (*Centrocercus urophasianus*). From the 1890s until the late 1950s, black sagebrush plant communities in the Carson Desert of Nevada were a vital part of winter range for the domestic range sheep industry. Years of excessive browsing by sheep actually shaped the outline of black sagebrush shrub canopies; Zamora and Tueller (1973) reported they had difficulty in finding relic communities in high range condition.

Vegetation of the Buckskin Mountains of west central Nevada is characterized by black sagebrush/desert needlegrass (*Stipa speciosa* Trin. & Rupr.) plant communities. The Buckskin Mountains are located 100 km southeast of Reno, Nevada, in the rain shadow of both the Sierra Nevada and Pinenut Mountains. This is a portion of the Carson Desert in which Billings (1945) suggested that *Atriplex*-dominated salt desert shrub vegetation occurred because of atmospheric drought rather than occurrence of soluble salts in the soil. If we compare the black sagebrush communities of the Buckskin Mountains with those described in the regional study conducted by Zamora and Tueller (1973), we find that the highest-elevation, north-facing slope communities of the Buckskin Mountains correspond to the most arid communities previously described. From this we assume the black sagebrush communities in this study represent an arid extension of this type.

Only recently have occasional wildfires of any extent occurred in black sagebrush communities in western Nevada. The fires that have occurred have been associated with the recent spread of the alien annual cheatgrass (*Bromus tectorum* L.) into these arid environments (Young and Tipton 1990). Apparently for much

[1]USDA, Agricultural Research Service, 920 Valley Road, Reno, Nevada 89512

of the twentieth century these communities have not been subject to wildfires because of lack of herbaceous vegetation to carry the fire. Because of the lack of trees to produce fire scars, it is difficult to determine whether these sites were subject to periodic burning under pristine conditions. This is in sharp contrast to basin big sagebrush communities where periodic catastrophic stand renewal by burning from wildfires has been common. The lack of catastrophic stand renewal in black sagebrush communities should be reflected in the age/size class structure of the communities.

Our purpose was to determine the age/size distribution of black sagebrush plants to determine community structure.

MATERIALS AND METHODS

Studies were conducted from 1984 through 1988 in the Buckskin Mountains located about 100 km southeast of Reno, Nevada. The geologic features of this mountain range have been described in detail by Hudson and Oriel (1979). Vegetation and soils of the range have been mapped and related to the geologic map of the area (Lugaski and Young 1988). The plant communities used in this study were located on the Guild Mine member of the Mickey Pass tuff. This geologic unit consists of crystal-rich, moderately to poorly welded ash flow tuff (Proffett and Proffett 1976). It has been proposed that the soils (a) developed in place, (b) developed from subaerially deposited material from long-distance transportation, or (c) developed from a combination of residual and subaerially deposited material (unpublished research, ARS-USDA). The bulk of the profile is an argillic horizon, about 50 cm thick, which consists of 50% or more clay-textured material. It is proposed that this clay horizon is a relic of a soil that developed on the site and whose original surface horizon has been removed by erosion. The important point is that the clay horizon, which is intermittently exposed on the soil surface, developed under different environmental conditions from the current surface horizon. The current surface soil consists of a relatively recently deposited layer, apparently from subaerial deposition, that is largely confined to mini-mounds beneath the canopies of the black sagebrush plants. The soil is classified as a fine, iridic, montmorillonitic, Typic Paleargid.

Spatial structure of the black sagebrush communities was determined by sampling five stands located along the western flank of the Buckskin Mountains. The five stands, located on the same outcropping of Mickey Pass tuff, were separated by small canyons where the westerly tilted ash flows were broken by faulting. All sites were west facing and located in a band along the mountainside at 1720–1780-m elevation.

A starting point was located on aerial photographs in each stand, and 10 plots, each 10 m^2 in area, were located randomly along line transects parallel to the slope. A total of 50 plots were established (5 stands × 10 plots per stand). In each plot the following were determined: (a) shrub density by species, (b) crown cover of shrubs (ocular estimate), (c) shrub height, (d) area of mound and interspaces, and (e) herbaceous cover (ocular estimate). Mound cover refers to the slightly raised areas beneath shrub canopies where subaerially deposited soil and saltation deposits accumulate.

At each plot location the herbaceous vegetation frequency was sampled with 100 step points arranged in 4 lines of 25 points each following the procedures of Evans and Love (1957). The herbaceous vegetation was resampled annually.

Using the same starting point, but by placing the transects up and down the slope, 25 black sagebrush mounds were located in each stand. The shrubs rooted on each mound were measured for (a) height, (b) maximum and minimum crown diameter, (c) stem number (as black sagebrush ages the cambium splits, forming multiple-stemmed plants), and (d) stem diameter at the soil surface (diameter of the group of split stems). The aerial portion of the plant was subdivided by clipping into the following categories: (a) coarse stems, 2.5 cm or larger in diameter; (b) fine stems, 0.25 to 2.4 cm in diameter; (c) current annual growth; and (d) leaves. The material was dried at 80 degrees C for 24 hours and weighed.

After the aerial portion of the shrub was removed, the litter beneath the canopy was collected and screened through a 2-mm screen. The material too coarse to pass through the screen was saved, dried, and weighed. The maximum and minimum diameters of the mound were measured, and the height of the mound was determined by digging to the clay horizon. The number of perennial grasses rooted on the mound was counted by species, and the cover of cheatgrass was estimated ocularly per mound.

A series of age/size classes was established for the black sagebrush plants sampled. These

TABLE 1. Mean plus standard error (SE) for shrub density per m^2, percent projected canopy cover, frequency (10-m^2 plot) within stands (N = 10), and constancy among stands (N = 5).

Species	Density (m^2)	SE	Cover (%)	SE	Frequency (%)	SE	Constancy (%)	SE
Artemisia nova	2.2	0.40	22	2.4	100	0	100	0
Chrysothamnus viscidiflorus	0.7	0.10	2	0.4	40	8	80	8
Ephreda nevadensis	0.3	0.08	1	0.4	64	10	100	0
Tetradymia glabrata	0.2	0.04	–[a]	–	32	5	60	4
Eriogonum microthecum	0.1	0.04	–[a]	–	5	1	20	2
Eriogonum umbellatum	0.2	0.00	–[a]	–	8	1	20	1

[a]Indicates less than 1% average cover

classes were based on the size, growth form, percentage dead canopy, and apparent age of the plants. The classes were (a) seedling, (b) young plant, (c) mature plant, (d) patriarch, (e) senescent, and (f) dead.

Soil samples from the surface 5 cm were taken (a) next to the shrub stem, (b) at the canopy edge, and (c) 10 cm beyond the edge of the shrub canopy. These samples were dried, screened, and shipped to a commercial laboratory for nitrate nitrogen analysis.

A two-way analysis of variance and post hoc Duncan's Multiple Range test were performed to analyze differences in soil nitrate concentration between sagebrush age/size classes and sample location. A series of stepwise regressions was performed, utilizing the general linear model, wherein a subset of variables was chosen that would best predict plant weight, annual growth of plant (weight), and leaf weight of black sagebrush. Separate step-up regressions were performed for plant and mound characteristics (Neter and Wasserman 1974). The independent variables that were significant contributors to predicting age/size classes for these two groups were chosen as discriminant variables to be used in two separate discriminant analyses. The age/size classes of the sagebrush plants were used as the grouping structure in the discriminant analysis. The plant characteristic variables selected as significant contributors to classification into age/size classes were (a) weight of coarse stems, (b) number of stems, (c) plant height, and (d) plant diameter. The mound characteristics (ranked in order of importance) used were (a) litter cover, (b) litter weight, (c) soil nitrate concentration, and (d) cheatgrass cover on the mound.

RESULTS AND DISCUSSION

Community Competition

The plant communities of the Buckskin Mountains dominated by black sagebrush are low in diversity (Table 1). Green rabbitbrush [*Chrysothamnus viscidiflorus* (Hook.) Nutt.] occurs in patches in the community. Nevada ephedra (*Ephedra nevadensis* Wats.) is rather evenly distributed through the black sagebrush communities, but at a low density. Littleleaf horsebrush (*Tetradymia glabrata* Gray) is a relatively infrequent component of the communities. The two species of *Eriogonum* are semiwoody species that also occurred in the most arid black sagebrush communities that Zamora and Tueller (1973) reported.

Squirreltail (*Elymus hystrix* Scribn.) and cheatgrass are the most frequent herbaceous species (Table 2). The relative frequency of the two species reverses from year to year depending on available moisture for plant growth. Cheatgrass is abundant only in years with adequate moisture during the spring. The density of squirreltail plants remains relatively constant. In dry years, squirreltail is virtually the only herbaceous species in these communities.

Biomass

Along the western margin of the Buckskin Mountains, black and basin big sagebrush communities occur side by side on sharply contrasting soils. The basin big sagebrush communities have been burned in wildfires, based on historic records and fire scar analysis (Young et al. 1989). Our analysis of black sagebrush communities is essentially based on aboveground woody material accumulation of the dominant shrub. We had previously conducted a study of the biomass

TABLE 2. Mean plus standard error (SE) for frequency of herbaceous species for an average of four years' sampling (average precipitation 175 mm), for a dry spring (1989, no April precipitation), and a year with above-average moisture available for plant growth (1986, 225 mm precipitation). Based on 5000 sample points per year.

	Frequency					
	Average		Dry (1989)		Wet (1986)	
	Four years	SE	Spring	SE	Spring	SE
GROWTH FROM SPECIES	%					
PERENNIAL GRASS						
Elymus hystrix	39	4.1	70	6.9	6	0.5
Stipa speciosa	3	0.3	8	0.7	–	–
Stipa thurberiana	–[a]	–	–	–	–	–
Poa secunda	–		1	0.8	–	–
Oryzopsis hymenoides	–	–	1	0.2	–	–
ANNUAL GRASS						
Bromus tectorum	44	6.6	14	2.8	76	3.8
PERENNIAL FORB						
Castilleja chromosa	1	0.2	1	0.2	–	–
Sphaeralcea parvifolia	–	–	2	0.3	–	–
Phlox hoodii	–	–	3	0.3	–	–
ANNUAL FORB						
Erodium cicutarium	5	0.8	–	–	2	0.8
Descurainia pinnata	–	–	–	–	5	0.7
Sisymbrium altissimum	5	0.9	–	–	10	0.8

[a]indicates less than 1% average cover

of basin big sagebrush adjacent to the western edge of the Buckskin Mountains (Young et al. 1989). This allowed comparison of the production of biomass of basin and black sagebrush from the same area. The basin big sagebrush community had a sandy loam surface soil and a greater soil depth (Haplargids derived from metavolcanic sources). Big sagebrush ages were clumped at 55–60, 40–45, and 10–15 years old.

The general aspect of the two communities is strikingly different, with the maximum height of the black sagebrush being 60 cm and that of the big sagebrush over 1 m. In contrast to the central woody stems of the big sagebrush plants, black sagebrush plants appear multi-stemmed. Despite the difference in height, the two communities have similar biomass because of the higher density of plants in the black sagebrush community. There is more coarse and fine woody material in the basin big sagebrush community (Table 3).

If we assume both populations are the same age (assumption is necessary because actual age of black sagebrush plants could not be estimated), the rate of woody biomass accumulation was 13.2 g/m^2/year and 64.5 g/m^2/year for black and basin big sagebrush, respectively. The wide difference between the two communities is apparently due to the higher woody biomass of more mature basin big sagebrush plants.

Woody biomass of black sagebrush was best predicted by the equation:

$$Y = 9.87 + 1.21 * X1 + 1.12 * X2 + 0.88 * X3$$

where Y = total woody biomass (grams), X1 = fine stems, X2 = coarse stems, and X3 = root crown. R^2 = .96 for this determination. Yearly growth increment was predicted by the equation:

$$Y = 16.96 + 0.26 * X1 + 0.16 * X2 - 0.73 * X3 - 0.14 * X4$$

where Y = current growth, X1 = fine stems, X2 = coarse stems, X3 = plant height, and X4 = root crown. R^2 = .57 for this determination, despite the inclusion of a fourth variable. Our third equation predicted leaf weight:

$$Y = 23.53 + 0.29 * X1 - 0.93 * X2 + 0.2 * X3 - 0.35 * X4$$

where Y = leaf weight, X1 = coarse stems, X2 = height of plant, X3 = fine stems, and X4 = plant density. These four variables in the equation accounted for 64% of the variability in the data.

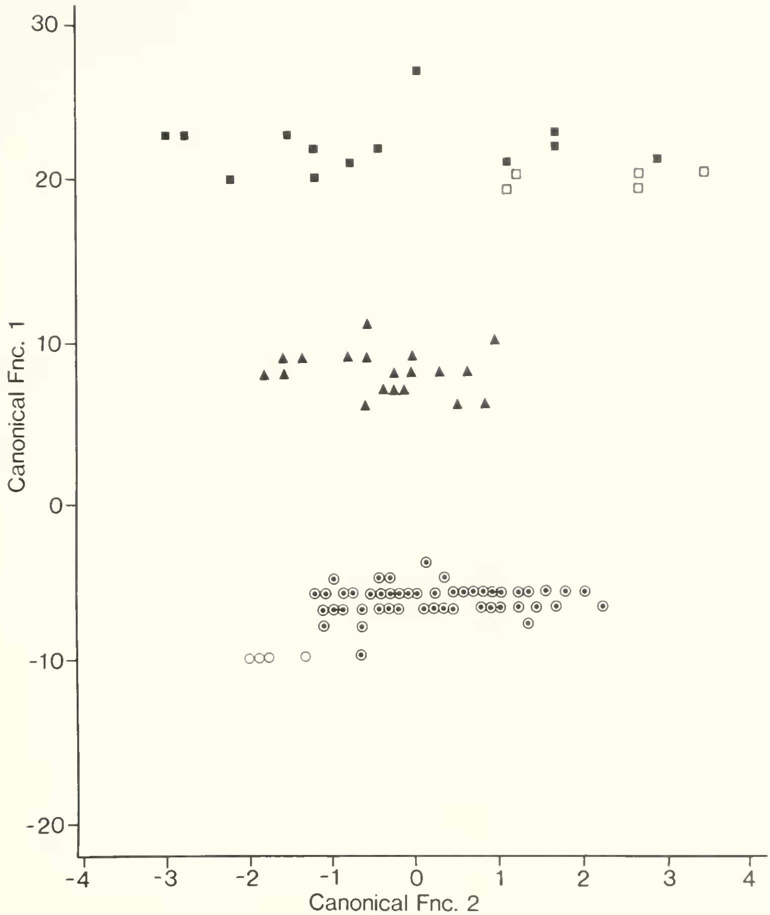

Fig. 1. Plot of black sagebrush group membership based on plant characteristic discriminant equations where ○ = young, ⊙ = mature, ▲ = patriarch, ■ = senescent, and □ = dead.

Age/Size Classes

The selected variables for both plant and mound characteristics were important contributors in distinguishing between age/size classes and were good indicators of group composition (Fig. 1). Very few misclassifications occurred by use of the resulting discriminant functions.

The bulk of the black sagebrush stands was composed of mature plants 20–60 cm tall with canopies 20–50 cm in diameter (Table 4). This is a wide range in height and canopy size, but the mature age/size class was distinguished from young plants by the presence of up to 10% dead material in the canopy and the beginning of the separation of the stem into individual cambium bundles. The patriarch class was distinguished from the mature class by an increase in dead material in the canopy (to 30%) and complete separation of the stems. The separated stems formed U-shaped flutes with the open end of the U toward the former center of the stem. It was not possible to establish the maximum age of the class because the center of the stem was missing. The individual section had at least 40 growth rings.

Senescent plants formed the next, apparently older, age/size class. In this class at least 50% of the canopy was dead. Older black sagebrush plants do not get taller, probably because they have no central stem to support the canopy. The diameter of the crowns does increase. There is a marked increase in woody biomass between the patriarch and senescent classes.

Seedlings and young plants constituted only 6% of the black sagebrush populations (Table 4).

TABLE 3. Mean density (stems/m^2) plus standard error (SE) and oven-dry biomass (g/m^2) of *Artemisia nova* and *A. tridentata* subsp. *tridentata*. Data for *A. tridentata* subsp. *tridentata* from a previous study (Young et al. 1989).

Species	Density		Biomass per m^2									
			Coarse		Fine		CAG		Leaves		Total	
	m^2	SE	g	SE	g	SE	g	SE	g	SE	g	SE
Artemisia nova	2.2	0.4	750	90	520	60	180	45	130	40	1550	240
Artemisia tridentata subsp. *tridentata*	1.1	0.3	850	100	970	110	170	40	130	50	2120	420

TABLE 4. *Artemisia nova* crown and biomass characteristics for individual age/size classes. Demographic breakdown of black sagebrush communities by growth classes. Classes are related to age for younger plants, but once stems separate, ages are not based on annual rings.

Age size class	Crown characteristics				Biomass characteristics						
	Height (cm)	Diameter (cm)	Density (%)	Dead branchlets (%)	Coarse stems (g)	Fine stems (g)	CAG (g)	Leave (g)	Stem number	Percentage of stand	Age (years)
Seedling	5	5	30	0	0	15	5	10	1	>1	2–5
Young plant	10–20	5–10	50	0	28	64	30	40	1	5	5–30
Mature	20–60	10–50	80	10	140	120	80	60	Multiple	60	30–50
Patriarch	20–60	20–80	60	30	560	420	140	100	Multiple	17	40+
Senescent	20–60	20–100	30	60	980	640	60	30	Multiple	12	?
Dead	20–60	20–100	0	100	910	320	0	0	Multiple	5	?

with seedlings being very rare. The separation between seedling and young plants was based on the occurrence of coarse, woody biomass in the latter class. Young plants had entire stems with no evidence of division of the cambium.

Mound Types

Each black sagebrush age/size class had a corresponding type of sub-canopy mound. The only seedling found in the entire study was located in an interspace between mounds. Obviously, one seedling is not a valid sample, but the lack of seedlings is a critical factor in the dynamics of the communities studied. The first detectable mound occurred under young plants. Only 5–10% of the sub-canopy area under black sagebrush plants in the young plant age/size class was covered with litter (Table 5). The litter was composed of fragments of black sagebrush leaves.

In the mature plant age/size class the cover of litter and the weight of litter increased (Table 5). The mounds were easily distinguished by both height and surface soil color and texture. The surface of the mounds appeared darker in color, and the reddish tinge to the clay surface soils of the interspace was not apparent. If the surface of the mound was disturbed, the dark color was replaced by a grayish shade. Mounds appear to reach their maximum height with this growth stage of black sagebrush. Mounds of mature plants had perennial grasses associated with the sub-canopy area. The most frequent perennial grass was squirreltail.

Litter accumulations increased with the patriarch age/size class, but height of the mound did not increase. Apparently, trapping of subaerial deposition material and saltation particles must be related to growth stage of black sagebrush plants in terms of crown architecture. Subaerially deposited particles are obviously very unstable and subject to redeposition if they fall in the largely bare interspace among shrub mounds (Young and Evans 1986). If litter accumulation increases on patriarch mounds, why do they not trap these secondary erosion products and the mound keep growing in height? Canopy structure changes with the patriarch age/size class, with increasing bare stems and spreading, but not taller, plants. It would appear that aerial dynamics of the crown of black sagebrush plants influence mound height.

With the senescent age/size class, a divergence

TABLE 5. Mound characteristics in relation to age/size classes of *Artemisia nova*. Illustrates that mound characteristics change with age/size classes of shrubs.

Black sagebrush growth classes	Mound Height (cm)	Mound Diameter Max (cm)	Mound Diameter Min (cm)	Litter Cover (%)	Litter Depth (cm)	Litter Weight (g)	Perennial grass density (per mound)	Cheatgrass cover (%)	Number Samples
Seedling	0	0	0	0	0	0	0	0	1
Young plant	2–5	60	30	5–10	0.5	40	0	2	6
Mature	5–15	80	40	40–60	1–1.5	480	2.0	15	76
Patriarch	10–15	100	60	80	2–3	690	2.8	12	21
Senescent	10–15	100	60	80	2–3	720	2.1	60	15
Dead	10–15	100	60	80	2.5–5	970	6.4	5	6

TABLE 6. Mean nitrate level (mg/kg) of soil at the stem, canopy edge, and outside the canopy of black sagebrush plants in relation to maturity classes, Buckskin Mountains, Nevada.[a]

Age/size class	Location[b] Stem (ppm)	Canopy (ppm)	Outside (ppm)	Age/size class mean[c]
Young plant	4.7 h	4.3 hi	4.1 hi	4.4 d
Mature	6.6 g	5.5 g	4.0 j	5.4 c
Patriarch	10.5 d	12.0 b	8.0 e	10.2 a
Senescent	13.2 a	11.3 c	7.0 f	10.5 a
Dead	8.4 c	7.0 f	7.1 f	7.5 b
Mean location[b]	8.7 a	8.0 b	6.0 c	

[a]Means followed by the same letter are not significantly different at the .01 level of probability as determined by Duncan's Multiple Range test.
[b]Means of location followed by the same letter are not significantly different at the .01 level of probability as determined by Duncan's Multiple Range test.
[c]Means of age/size classes followed by the same letter are not significantly different at the .01 level of probability as determined by Duncan's Multiple Range test.

in herbaceous species composition on the mounds occurs (Table 5). Some mounds become densely covered with cheatgrass as black sagebrush plants become senescent and others support colonies of squirreltail.

After the black sagebrush plants die, litter weight continues to increase and litter changes in appearance. Litter under dead plants is composed of stringy bark fragments, and individual black sagebrush leaves cannot be distinguished in the litter.

Soil Nitrate Levels

Surface soil nitrate levels were higher beneath shrub canopies than in the interspace (Table 6). Levels were highest next to shrub stems. Nitrate levels beneath the canopy rose as age/size classes of black sagebrush indicated older plants and mounds. This is in itself an indication that age/size classes actually do reflect increasing age. The development of vertical and horizontal patterns in soil nitrogen, attributed to the localization of litter fall beneath the canopies of desert shrubs, has been documented by the research of N. E. West and co-workers (Charley and West 1977, West and Skujins 1977, West 1979). Nitrate levels of surface soils dropped significantly ($P \leq .01$) once the black sagebrush plants died. Nitrate levels in surface soils at the edge of shrub mounds increased with apparent increasing age of black sagebrush plants and mounds. These areas correspond to the micro-topoedaphic situation described as coppice benches by Eckert et al. (1989) for shrub mounds in big sagebrush communities. Apparently the increase in soil nitrate results from leaching from the mounds. Once black sagebrush plants are dead and grasses dominate the mound, soil nitrate levels decrease.

Mounds and Black Sagebrush Community Structure

We did not find grass-dominated mounds or grass-dominated mounds with black sagebrush seedlings. We did note the remains of mounds that appeared to be eroding away. Apparently, mounds are dynamically formed and eroded in relation to the establishment and eventual death of black sagebrush plants. The failure to find grass-dominated mounds may be a function of herbivory by domestic livestock [sheep, feral horses (*Equus caballus*), and black-tailed jackrabbits (*Lepus californicus*)]. Grass-dominated mounds may fail to persist since grasses cannot maintain mounds because of leaf fall and canopy structure differences compared with black sagebrush plants. The only patchy vegetation encountered in the communities was groups of rabbitbrush plants. Perhaps rabbitbrush increases after relatively short-lived squirreltail plants die or are reduced by grazing. In an adjacent big sagebrush community we previously determined three episodes of seedling establishment at 12, 42, and 57 years before 1985 (Young et al. 1989). Plant ages were clustered around these apparent establishment dates. The clusters may represent periods of desirable climate for seedling establishment or a single season when establishment occurred; they may also represent variability in growth ring deposition or recognition. The classes we constructed in this study are much too broad to pinpoint this type of episodic stand establishment for black sagebrush. Perhaps black sagebrush communities not renewed catastrophically by wildfires only require stand renewal at such low levels (5% of the stand, standing dead plants) that our one seedling sampled is sufficient for community regeneration.

LITERATURE CITED

BEETLE, A. A. 1960. A study of sagebrush. Bulletin 368. Agricultural Experiment Station, University of Wyoming, Laramie.

BILLINGS, W. D. 1945. The plant associations of the Carson Desert Region. Western Nevada Butler University Botanical Studies 7: 89–123.

BLAISDELL, J. P., AND R. C. HOLMGREN. 1984. Managing Intermountain rangelands—salt desert shrub ranges. General Technical Report INT-163. Forest Service, USDA, Intermountain Forest and Range Experiment Station, Ogden, Utah. 52 pp.

CHARLEY, J. L., AND N. E. WEST. 1977. Micro patterns of nitrogen. Mineralization activity in soils of some shrub dominated semi-desert ecosystems of Utah. Soil Biology and Biochemistry 9: 357–365.

ECKERT, R. E., JR., F. F. PETERSON, M. K. WARD, W. H. BLACKBURN, AND J. L. STEPHENS. 1989. The role of soil-surface morphology in the function of semiarid rangelands. Nevada Agricultural Experiment Station Bulletin TB-89-01. University of Nevada, Reno.

EVANS, R. A., AND R. M. LOVE. 1957. The step-point method of sampling. A practical tool in range research. Journal of Range Management 10: 208–212.

HUDSON, D. M., AND W. M. ORIEL. 1979. Geologic map of the Buckskins Range, Nevada. Map 64. Nevada Bureau of Mines and Geology, Mackay School of Mines, University of Nevada, Reno.

LUGASKI, T. P., AND J. A. YOUNG. 1988. Utilization of LANDSAT thermatic mapper data and aerial photography for mapping the geology, soils and vegetation assemblages of the Buckskin Mountain Ranges, Nevada. American Congress on Surveying and Mapping and American Society for Photogrammetry 1988: 218–227.

NETER, J., AND W. WASSERMAN. 1974. Applied linear statistical models. Richard D. Irwin, Inc.

PROFFETT, J. M., JR., AND B. H. PROFFETT. 1976. Stratigraphy of the Tertiary ashflow tuffs in the Yerington district, Nevada. Nevada Bureau of Mines and Geology Report 27. Mackay School of Mines, University of Nevada, Reno. 28 pp.

WEST, N. E. 1979. Formation, distribution, and function of plant litter in desert ecosystems. Pages 647–659 *in* R. A. Perry and D. W. Goodall, eds., Aridland ecosystems: structure, functioning and management. Vol. 1. International Biological Programme 16. Cambridge University Press, London.

WEST, N. E., AND J. SKUJINS. 1977. The nitrogen cycle in North American cold-water semi-desert ecosystems. Ecologia Plantarum 12: 45–53.

YOUNG, J. A., AND R. A. EVANS. 1986. Erosion and deposition of fine sediments from playas. Journal of Arid Environments 10: 103–115.

YOUNG, J. A., R. A. EVANS, AND D. E. PALMQUIST. 1989. Big sagebrush (*Artemisia tridentata*) seed production. Weed Science 37: 47–53.

YOUNG, J. A., AND F. TIPTON. 1990. Invasion of cheatgrass into arid environments of the Lahontan Basin. Pages 37–41 *in* E. D. McArthur, E. M. Romney, S. D. Smith, and P. T. Tueller, compilers, Proceedings of the Symposium on Cheatgrass Invasion, Shrub Die-off, and Other Aspects of Shrub Biology and Management. General Technical Report INT 276. Forest Service, USDA, Ogden, Utah.

ZAMORA, B., AND P. T. TUELLER. 1973. *Artemisia arbuscula*, *A. longiloba*, and *A. nova* habitat types in northern Nevada. Great Basin Naturalist 33: 225–242.

Received 21 October 1991
Accepted 10 September 1992